ELECTRIC TOWAGE

ON

RIVERS AND CANALS.

REPRINTED FROM "ENGINEERING."

LONDON:
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AMONG the papers read before the spring meeting held by the Institution of Mechanical Engineers, was one on "Mechanical Propulsion on Canals," by Mr. L. Robinson.* The present, and some subsequent articles, will deal in a more detailed manner with one of the subjects touched on briefly in the communication referred to. In France towing boats (*bateaux toueurs*) are known as those that haul one or more barges by drawing on a chain that is submerged in the water for the whole length of their course. Tugs (*remorqueurs*), on the other hand, are those vessels that haul a train of barges by means of the propelling power—screws, for example—with which they are fitted. The comparative advantages of the two systems depend on the *régime* of the canal or river over which the traffic is conducted. The former method is more advantageous against a rapid current, as there should be no slip between the chain and the hauling machinery; the tow-boat bears in reality on a fixed point, and progresses only by the exact amount it advances on the chain. The tug-boat, on the other hand, in going against a stream, not only covers the actual distance between two given points, but has also to overcome the leeway due to the current.

Admitting what has been demonstrated by experiment, that the efficiency of side wheels, or a screw, applied to towing is half that due to chain haulage, it can easily be proved, that in going up stream, the relation between the work T done by a tug and that of T o done by an equivalent chain haulage boat, that is to say, with an effort sufficient to take the same number of barges against the same stream and at the same speed, is given by the formula

$$\frac{T}{T\ o} = \frac{2\,(V + S)}{V}$$

in which V is the speed of the train of boats in relation to the banks of the river, and S the rate of the current. The results of many experiments that have been collected confirm the accuracy of this formula with narrow limits. It follows, therefore, that in dead water a chain haulage with a force of 100 horse-power is equivalent to a tug of 200; and that against a current, 100

* See "Engineering," Vol. lxiii, pages 583, 591, 602, 627, and 832.

horse-power in the former is equal to 400 in the latter, if the speed of the convoy is equal to that of the current; while the difference increases rapidly as the speed of the tow falls below that of the current.

In practice the speed of hauling is less than that of the current, when the latter is equal to, or in excess of, 1 metre per second. Higher speeds are not practicable with cheap rates of water transport. For example, if the speed of current is equal to 3 metres, and that of the convoy is .60 metres (which would be a satisfactory rate), a chain haulage of 100 horse-power would be equivalent to a tug of 1,200 horse-power. These figures prove clearly the advantages possessed by the chain-haulage system in going up rivers against a rapid stream, and the advantages increase with the velocity of the current. They are measured by the difference between the economy of coal, and the special expenses inherent to the chain system, so long as it is possible to employ tugs; but they become absolute with currents of high velocity, and particularly in very shallow waters, for chain haulage can be made successful with a simple raft, while steam tugs of considerable power require a greater depth of water.

It is evident that the many advantages of the chain (except that of draught) in going up-stream disappear in coming down. Further, while it is not practicable to tow a convoy up stream against a rapid current, it may be also impracticable to tow a similar convoy down the same current, on a chain. In practice, it is not feasible to unwind a heavy chain by means of winches, for if the speed of these becomes considerable, the mechanical operation is dangerous. Now the speed of the chain tow boat is necessarily that at which the winches are revolved, or what is the same thing, that at which the chain is unwound. This speed cannot be increased indefinitely; if in running as quickly as is practicable the speed obtained is but little greater than that of the current, the boats will have only an insignificant speed relative to the current, the rudders are practically useless, and the situation becomes dangerous. If the chain is unwound as rapidly as is reasonably possible, the speed given to the towing boat may be less than that of the current, especially in places where for certain reasons it is extremely rapid. In this case the boats will advance with the same velocity as the current, that is to say, faster than the towing boat, a condition of things obviously impracticable.

We have defined the "Toueur" in saying that it hauls upon a chain submerged for the whole length of the course to be traversed. In principle the same definition would apply if a cable were employed instead of a chain, and, in fact, this modification has been tried in a number of instances, but never with satisfactory results. This failure is due to several causes, only one of

which need be referred to here—the want of sufficient weight in the cable. This gives no trouble, so long as the course lies along a straight line. The cable (which, like the chain, is sunk in the bed of the river, and is raised to pass over the winches on the boat, to fall again into the stream over the stern), being much lighter than the chain, is raised from the bed for a greater distance than the latter, with the same tractive effort, and this has no inconvenience so long as the course is straight. But on curves and bends the raised length of the cable or chain has, of course, a tendency to straighten, and to form a chord to the arc on which it was originally laid, and the chord approaches nearer to the centre of the curve, the greater the length raised. In the case

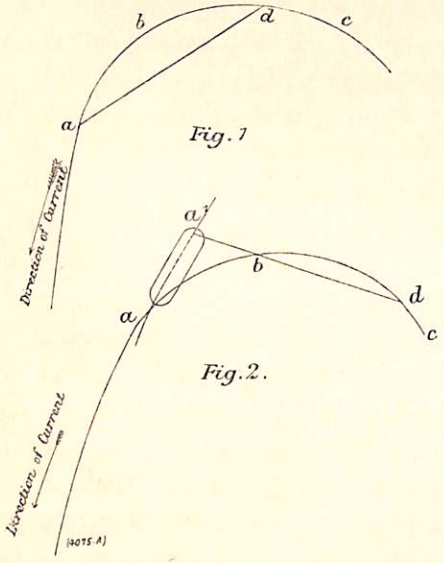


Fig. 7

Fig. 2.

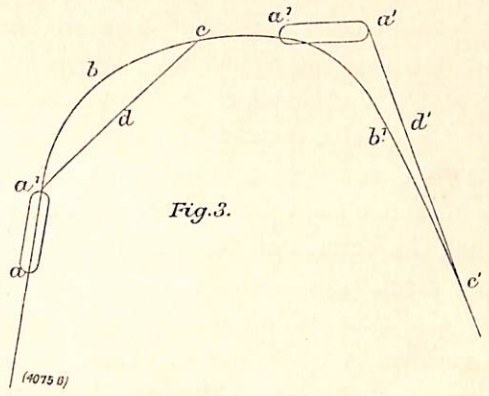


Fig. 3.

of a curve of small radius, and with a considerable tractive effort, a cable may strike the inner bank of the river, as has frequently happened in experiments with this method, as on the Erie Canal, the Moscova, in Russia, and elsewhere. And not only is the cable thrown disastrously out of the proper line, but the tow, moored fore-and-aft by the cable passing over it, is dragged out of its course and becomes unmanageable. The advantages of the chain are therefore beyond discussion as compared with the cable, and the more sinuous course of the stream, the more heavier must be the cable, and the greater the tractive effort. The chain, moreover, has the advantage of being adapted to roll around drums of smaller diameter than a cable of the same strength, and in this respect it possesses a superiority.

This leads to another consideration in the question of chain haulage. If

a b c, Fig. 1, show the normal position of the chain on a curve that has to be traversed by a convoy, the chain boat being at a, the raised portion of the chain would occupy the position a d, drawing the boat in the same direction. If the chain-haulage traffic is wholly up-stream, it is essential that each of the boats should be so arranged that it should allow the chain to fall behind it in its normal position, and that it should therefore be able to resist the effort of the chain to drag it nearer the centre of the curve, and should be able to keep it in such a position as is indicated in Fig. 2 by the point a, where the chain falls into the water at the rear of the boat, describing the curve a b c, the forward part being held outside this curve, and the raised chain taking a position on the line a d. But at the moment when the boat is entering the curve, Fig. 3, it is clear that the length of the chain following a^1 d c is less than on the line a b c, and that consequently a greater length of chain has been rolled up forward than corresponds to the distance traversed. At the moment of leaving the curve, the quantity of chain along a a^1 c^1 is greater than that on a^1 b^1 c^1; and the course to be traversed by the rear of the boat is greater than that forward; it is necessary, therefore, that the boat should unwind more chain aft than it receives forward. In order that the normal condition should be maintained after the passage of the convoy, and, indeed, that the transit of the curve should be properly made, it is necessary that the slack of the chain should not be allowed to fall back into the water at the moment when the boat enters the curve, but it must be kept on board to be made use of while passing the curve; consequently it follows that means must be provided to regulate the discharge of the chain from the stern of the boat. In this also the chain possesses a considerable advantage over the cable, which cannot be so easily handled.

The foregoing paragraphs explain why, in dealing with the question of boat towage on this system, we limit ourselves to haulage by chain, the only method that has been proved practical. The essential condition to be filled is evidently to avoid all slip between the boat and the chain upon which it hauls. The boat resembles a locomotive, in that it must not slip on the chain any more than the engine may slip on the rails; it is, in fact, a locomotive exerting considerable tractive energy at necessarily very low speeds. After many tentative experiments, the history of which we will not pause to record, to secure complete adhesion between the boat and the chain, experience showed the most efficient to be a system of two winches with five grooves, driven at equal speeds by a steam engine. The chain in passing from one winch to the other makes four half-turns on each, and consequently there are

four complete turns on the whole. When a cord is wound around a cylinder, the ratio between the tensions Q and q of the entering and leaving ends is given by the formula

$$Q = q e^{f\phi}$$

in which e is a constant, f the coefficient of friction, and ϕ the total angle of winding; if this latter has a high value Q becomes very considerable however small q may be. In the particular case under consideration, the initial tension q is given by the weight of the chain falling into the after part of the boat; if it is insufficient of itself, it is easily increased by making the last groove of the winch drum of a slightly greater diameter than that of the others. This may be accomplished in a variety of ways: as, for example, on the Seine, where four or five small wooden wedges are driven into the groove at equal distances around its circumference. It is with such an apparatus that the first chain haulage installation was put into service on the Seine in 1856, and all subsequent installations on the Elbe, the Danube, the Mein, the Neckar, and the Cheskna, have similar arrangements. Figs. 4 to 7 are diagrams showing the general features of the first Seine boats of this kind. Fore-and-aft there are two turn-tables mounted on vertical axes; these receive the chain at its entry and exit when in turning curves the boat has to take an oblique direction. On quitting this guide the chain passes between the vertical guide rollers that fix its position on the boat along the deck, on which it is supported on a series of horizontal rollers mounted in a chain path between the vertical rollers and the winches. Between the winches and the engine a double set of gearing is provided, either of which can be started by a clutch; by means of these a considerable range in speed can be secured, according to whether the convoy is going up or down stream. The adhesion obtained by this arrangement is all that could be desired, but the system, however, possessed serious inconveniences. In the event—and this can scarcely be avoided—of unequal wear in the grooves, the chain is likely to be exposed to great and uneven strains, which the most careful inspection and maintenance cannot prevent; owing to this cause the hauling chain has been broken between the winches. Another more serious difficulty is due to the fact that the rolling of the chain round the winches, to which reference has been made, necessitates a variable length of chain according to diameters and distance apart of the winches, of from 50 to 80 metres. From this it follows that the boat, when it has gone up-stream to the end of its course, cannot quit the chain to go free down the river. If, for example, a boat in starting from below requires 50 metres of chain to throw off the same amount on

Fig.6.

Fig.4.

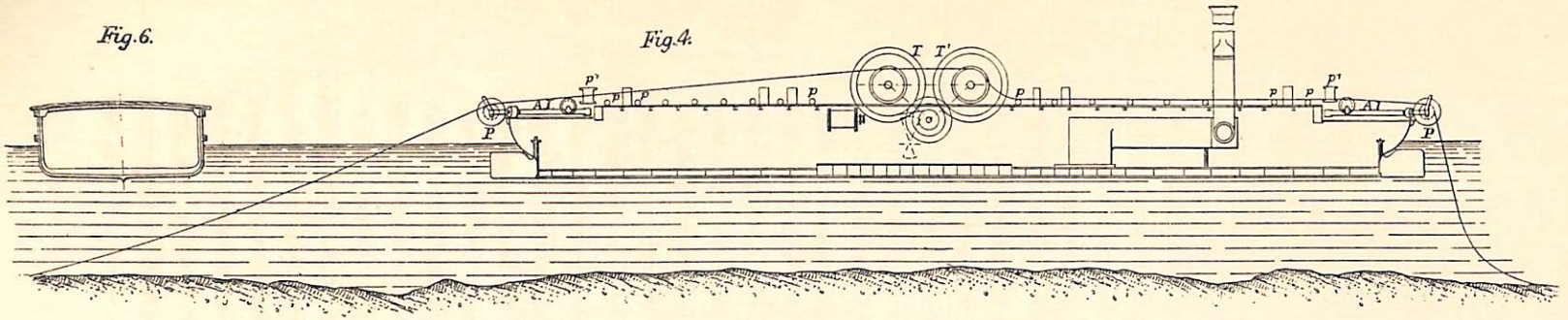


Fig.7.

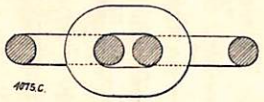
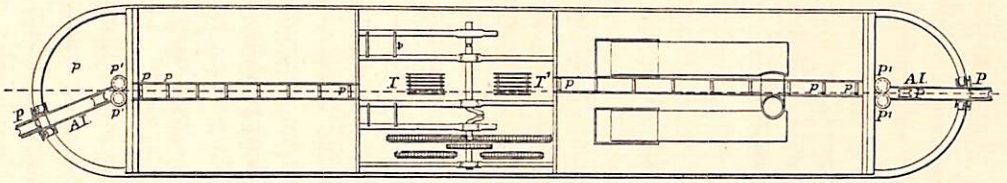


Fig.5.



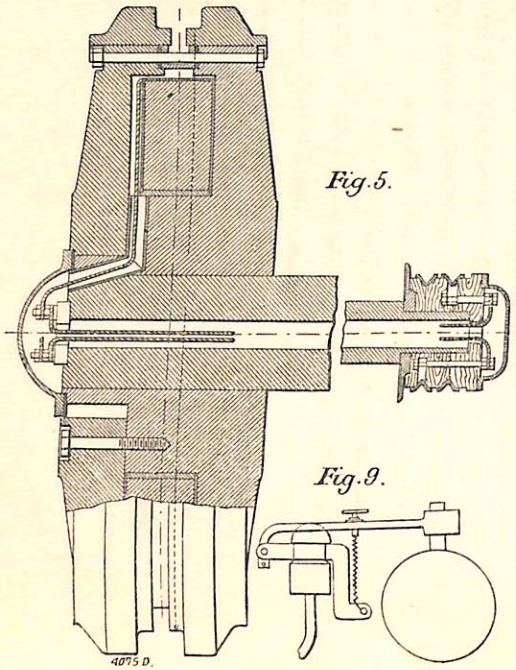


Fig.5.

Fig.9.

Fig.10.

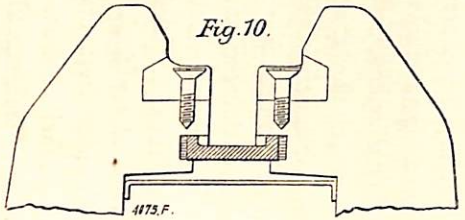


Fig.6

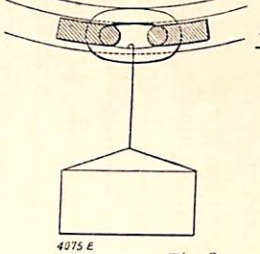


Fig.7.

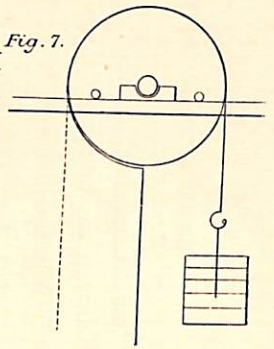
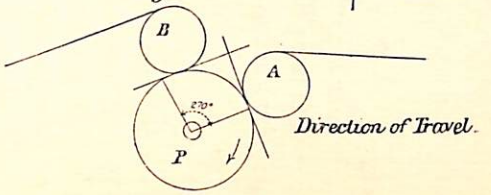


Fig 8



arriving at the upper end of its journey, the chain is shortened by so much, which is inadmissible. If, on the other hand, on arriving at the upper end the chain is separated and reconnected by a screw link, the terminal points do not change, but the chain is continually changing its position by a distance of 50 metres on each trip, some one of its parts coming successively over each point of the course. Now, the resistance due to the current is always variable at different points, and in order not to have an altogether too costly maintenance, it is necessary to always have the newest lengths of chain where the wear is the greatest, and the older chain along the easier parts of the channel. This system of shifting the chain has been tried on the Danube on tow-boats fitted with side wheels for coming free down stream, but the results obtained were very unsatisfactory. Failing this method, however, it is necessary that the boats should drive on the chain both in ascending and descending the stream; and it is on these lines that the system of haulage has been carried out everywhere except on the Danube. But as the chain system is, as we have seen, badly adapted to bring convoys down stream, the plan generally adopted is to bring the tow-boats down empty. Running alone and light, it is easy to take advantage of their mass and speed when going round curves to force the chain outward into the normal position for the ascending boats. By following this plan the maintenance of the chain is reduced to reasonable proportions; but, on the other hand, the economical conditions of traffic are badly provided for, as the convoys are taken only in one direction, and the door is opened to serious competition from independent tug-boats, while the up-stream service is much interfered with by the empty boats coming down. It should be added that, on the Danube, where, the boats being provided with their own power, do not descend on the chain, other means have been taken to keep the latter in its proper position. This was attempted by making a well aft of the winches on the boat, where the chain, not required to fall back at once into the water, could be stored, and between this well and the stern was placed a brake by which the discharge of the chain could be regulated.

It is evident that there can be no difficulty in providing a chain-haulage boat with side wheels or a screw, which in no way can interfere with the function of the boat in going up-stream, and which may be utilised in coming down. The ideal arrangement then depends on the application of a mechanism which requires only a relatively short length of chain—that is to say, that the amount of slack shall not exceed from 2 to 4 metres in length. Several efforts have been made in this direction with the use of special pulleys, but no good results have been obtained. Cables have also been tried with Fowler

pulleys, but besides the defects inherent to the use of cables for this purpose, which have been pointed out, the result was unsatisfactory. The large diameter of the pulleys proved inconvenient, and the amount of cable distributed over the various winches and the brake was very considerable. It was evident that some other solution was necessary.

As we have already stated, all the mechanical arrangements that have been devised to regulate the movement of the towing chain have proved unsatisfactory and complicated. Of a different order of ideas is the apparatus of M. de Bovet, a French engineer, who has sought to grip the chain by the action of an electro-magnet. To this end the chain was placed in contact with the closely adjacent poles of an electro-magnet in such a way as to close the magnetic circuit developed by the passage of an electric current. The magnetised pulley, which is illustrated in Fig. 5, is practically a solenoid with a soft steel core, the two ends of which are extended and brought close together in order to form the two flanges of the pulley. The links of the chain pass successively over this pulley, the one in a vertical plane and the next at right angles, with as little play as possible. The dimensions of the groove of the pulley are fixed by those of a new chain; it is, therefore, to be expected that with a chain already worn there would be a diminution in the adhesion, due to the reduced size of the links, and to its greater play. But it must be borne in mind that if the chain is properly maintained, those lengths of it which are the most worn would be re-laid along those sections of the canal where, the tractive resistance being reduced, a smaller amount of adhesion is required. It has to be remembered, also, that from time to time the chain will fail to pass truly between the jaws of the pulley; this may be caused either by the links twisting, which cannot be entirely avoided, or because of the coupling links employed to join up different lengths of chain, the size of which is unavoidably greater than that of the ordinary links. It is evidently necessary that the adhesion should be sufficient to prevent slipping under any conditions that may occur.

The first trials of this class of pulley were made with chain tow-boats built for service on the Seine below Paris, and for which it was necessary to obtain a tractive power of 5 tons. It was also necessary that the pulleys should not have too great a diameter, both to avoid complication in the transmission between the engine and the pulley, the circumferential motion of which is necessarily slow; and in order that the length of chain upon the tow-boat should be relatively small. For this last reason, it was necessary to employ only one pulley, around which the chain made less than a complete turn.

Under these conditions the tendency to slip, due to 5 tons' tractive strain, appeared considerable, if reliance was placed entirely on a magnetic resistance. But when the chain is rolled upon the pulley, the resistance to slip, due to the winding, has to be added to the direct effect of the magnetic attraction. This was clearly demonstrated by a series of trials made in the workshops, on a soft steel pulley 1.25 metres in diameter, and mounted on a trestle in such a way that it would not revolve. The magnetic coil consisted of 783 turns of wire 5 millimetres in diameter. The first experiments were directed to ascertain the limit of current which should not be exceeded, corresponding to the saturation of a new chain. This experiment is illustrated in Fig. 6; it consisted in placing one link and two half-links of chain at the lowest part of the pulley, and between its jaws, and in adding weights on a scale pan until the chain was torn from the pulley. It was found that beyond 48 amperes no increase of current gave any addition to the attraction. The chain employed had a diameter of 26.5 millimetres, and weighed about 15½ kilogrammes per metre. Under the same conditions of current an old section of chain, stretched and twisted, and reduced to a weight of 9 kilogrammes per metre, making three-quarters of a turn upon the pulley, as shown on Fig. 7, carried from 6 to 6½ tons without slipping, and without any initial tension on the loose end of the chain. But with this old chain, which completed the magnetic circuit less efficiently than the new chain, the adhesion was obtained by an exciting current much less intense than that corresponding to the saturation of the new chain; it did not exceed 18 amperes.

It was concluded from these experiments that the new chain making three-quarters of a turn over the pulley would give, with a current from 35 to 40 amperes, a resistance to slip of about 12 tons. This conclusion, however, could not be tested, as the arrangement of the experimental apparatus made it dangerous to suspend so heavy a weight. Moreover, there was no particular interest in pursuing this line of investigation, since it was proved that the oldest chain showed a greater resistance than would be met with in practice, on those sections of the channel provided with a new chain. If we call S the force of displacement (see Fig. 6), referred to 1 centimetre length of pulley, the same current which gives for the old chain a tangential adhesion of 6 tons, gives with the new chain, for E S (E being the total length passing round the pulley) scarcely four tons. These figures show clearly the power due to the effect of winding the chain. Wetting the chain with soapy water caused it to lose 10 per cent. of the adhesion obtained when dry. It was desirable to ascertain how much loss must be expected when the apparatus was

in operation, due to delays in the magnetisation of the chain as it passed over the pulley; but this would have involved experiments which, if not difficult, were at least costly; and it was decided that the results obtained with the pulley at rest showed the existence of a sufficient margin. The correctness of this conclusion was proved when the first tow-boat, furnished with magnetic adhesion, was put in service.

The chain in passing over the magnetic pulley must be held so securely as to avoid slip; but besides this, it is necessary that, arrived at the point of discharge, the chain should be set free to fall over the stern of the tow-boat. It is not difficult to imagine certain methods of magnetisation which would limit the effect upon the pulley between the points of entry and discharge the chain; but such methods are difficult to put in practice with the small diameter of pulley employed, and moreover, they would involve complications which were undesirable. The difficulty was overcome in a very simple manner; the chain passes around the pulley from 180 deg. to 270 deg. according to requirements, and, at its entrance and exit, is guided by smaller pulleys. The forward towage pulley ought to be very heavy, as there is an evident advantage in keeping one of its faces magnetically insulated as completely as possible, in order to avoid loss; and as this involves mounting the pulley at the end of the shaft, it is desirable to wind up the chain from underneath, because the effort of traction tends to relieve the weight. The arrangement thus worked out is shown diagrammatically in Fig. 8, when P is is the towage pulley and A, B the two guide rollers of the chain. There is an advantage in rolling the chain as little as possible around the pulley A, so as to avoid an exaggerated resultant strain; but the chain must pass round B at least 180 deg., which can be done without inconvenience, as the tension of the chain on the out-going links is negligable. But since there is a considerable winding on the pulley B, and since the normal strain on the pulley P is not great, B may be made a driving pulley with exactly the same linear speed in the groove on the pulley P; it may also be magnetised slightly, so that it pulls the chain from P, and also aids the chain to leave easily, since the attraction on it is very slight, and the point of leaving being nearly horizontal, the weight of the chain when moving in the proper direction aids in releasing it. The towage apparatus being thus arranged, it remains to adapt it to such conditions as will ensure easy maintenance; the manner in which this has been attempted is illustrated in Fig. 5. The pulley is mounted at the end of the shaft, to which the rear plate is keyed. The front plate is keyed to the rear plate, and locked by four pins; four unlocking screws are provided

for taking the pulley apart easily. The groove, which is the only surface exposed to wear, is formed of two rings adjusted and turned true on the plates themselves; they are held in position by screws and by magnetic adhesion. A gun-metal ring and rubber packing prevents the water and dirt, constantly brought in by the chain, from falling on the coil. The coil is inclosed in a close soldered brass box keyed on the boss of the pulley. The two wires, as shown in the drawing, are taken to the terminals at the end of the shaft. From these terminals wires are led through the hollow shaft to other terminals which are quite distinct from those of the coil; they are enclosed by a cast-steel cover. At the other end of the shaft the wires are secured to terminals either supported on porcelain insulators or mounted on blocks of varnished wood keyed on the shaft. Blocks of carbon rub on these terminals. The carbon blocks are fixed in porcelain insulators as shown in Fig. 9; the insulation remains perfect in spite of the condensation that exists so plentifully in a service of this character. The construction of the unwinding pulley (B, Fig. 8) is similar to that of the large pulley except as regards the groove. The two pulleys P and B, ought, as has been stated, to have the same linear speed; as B revolves faster it is more exposed to wear, although the work it has to do is slight; the groove of the pulley B has therefore to be so far modified as to adapt it to the same amount of wear as that of P. It is accordingly fitted, as shown in Fig. 10, with rings, made in two parts, carefully fitted and screwed in place; these can be easily renewed when they are worn. It may be mentioned that in pulleys P constructed as described, the wear after a year's hard service on two boats, amounted to 1 millimetre in one case and 1.5 millimetres in the other. On these boats the mean diameter of the grooves in the pulleys was 1.20 metres, and the coils were formed with 800 turns of 5-millimetre wire. The maximum current employed was 30 amperes. The diameter of the taking-off pulleys was .7 metre; the coils used for them had only 110 revolutions of 5-millimetre wire; they were mounted in series with that of the main pulley.

The length of chain required for passing around the towage pulleys, in the arrangement described, is only 3 or 4 metres. This particular desideratum, to which we have already referred, appears therefore to be met by the device of M. Bovet. The first boat of this type with magnetic adhesion gear was tried and put on service by the towage company of the Basse Seine, in 1893. It was fully described about that time at the fifth International Congress of Internal Navigation. (See the published Proceedings of that Congress; the Memoirs of the Société des Ingenieurs Civils, 1893; and the *Revue Universelle*, May, 1893.) Three other boats of a similar type have, more recently, been put in

service by the same company, and on these several modifications suggested by experience have been introduced. As regards the towing machinery, the changes have been very small, but alterations have been made in the construction and arrangement of the boats themselves, so that they differ considerably from the earliest model. The most recent type is illustrated in Figs. 11 to 16. The section of the Seine on which these boats are running is of considerable depth, and advantage has been taken of this fact to supplement the chain haulage with a screw propeller, and the form of the hull has been modified to suit this auxiliary propulsion. As on all boats of this class, where steerage is difficult on account of the action of the chain, two rudders are fitted, one forward and the other aft. The total length measured on the deck is 31 metres (101 ft. 8 in.), and the outside width is 5.470 metres (17 ft. 11 in.); the normal draught of water is 2 metres. The hull is divided into five watertight compartments by four bulkheads; forward there is a hold, and the accommodation for the deck hands, while aft there is a similar hold, and the living room of the machine hands. The engines are placed amidships, and the deck over them is raised 18 in. The construction of the hull and deck is very solid, as will be seen by reference to Fig. 17, page 16, where 1 and 2 are the forward and aft bulkheads, and 3, 4, and 5 are heavy double T transverse beams; 6 is a lattice stiffening girder. The girders *a*, *b*, with the transverse beams 2 and 3, enclose a hatchway, through which the boilers can be removed if necessary; *c* and *d* connect the transverse beams 3 and 4, and serve as a means of attachment of the chain brake, and of the tow-hook. The girders *e* and *f*, with the transverse girders 4 and 5, frame the engine hatchway. The chain well is shown at *g* and *h*. The brake *k* and the main frames *l* and *m* connect the lattice girder 6 to the forward bulkhead. The tow gear, that is, the two cables by which the convoy is attached to the tug, is fastened to the lattice girder 6. It is this girder, therefore, which has to resist the chief pull of the chain and the resistance of the tow. In the engine-room there are two internally-fired boilers with return flues, registered for a working pressure of 8 kilos. (114 lb. per square inch), and each with 50 square metres (538 square feet) of heating surface. A vertical compound engine drives gearing so arranged that it can transmit power to the screw or the chain apparatus. The system of transmission is shown in Figs. 12 and 14. That for the chain is from the main shaft to the driving pulley of the chain, by two toothed wheels keyed to the two shafts. As a general principle, the boat is only driven by the screw in coming down-stream, and the power required for this is higher than for the chain towage; the transmitted speed is therefore greater for the former than

ELECTRIC TOW-BOAT; BOVET SYSTEM.

CONSTRUCTED FOR THE COMPAGNIE DU TOUAGES DE LA BASSE SEINE ET DE L'OISE.

Fig. 11.

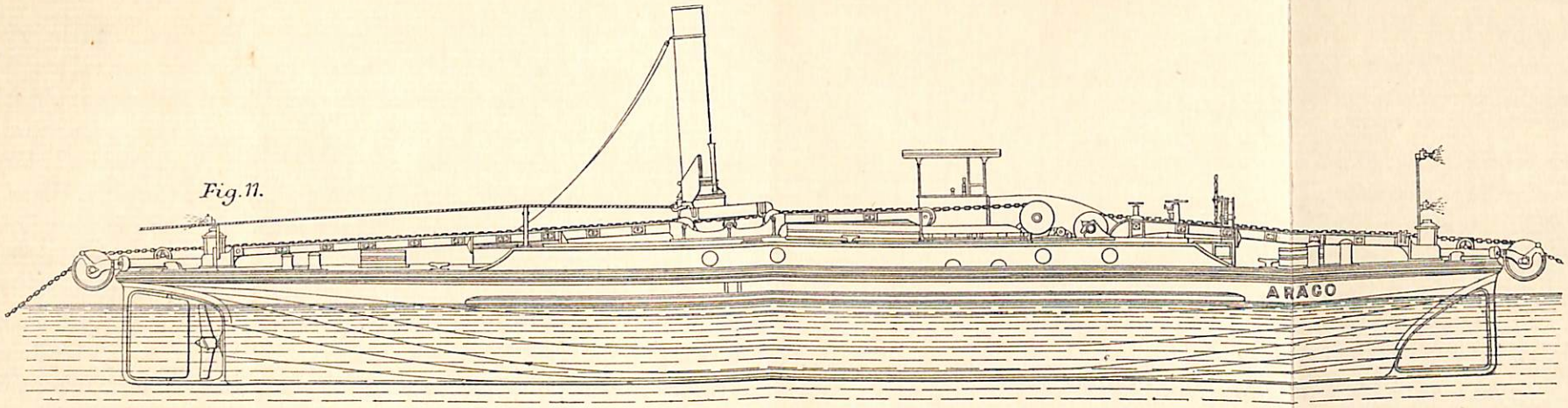


Fig. 15.

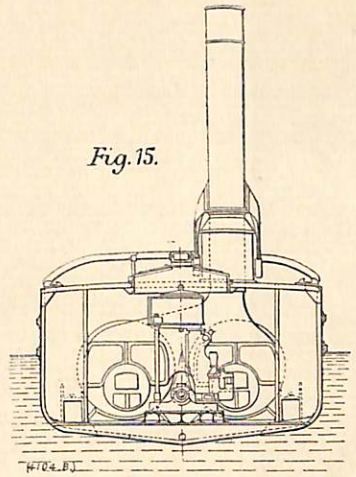


Fig. 12.

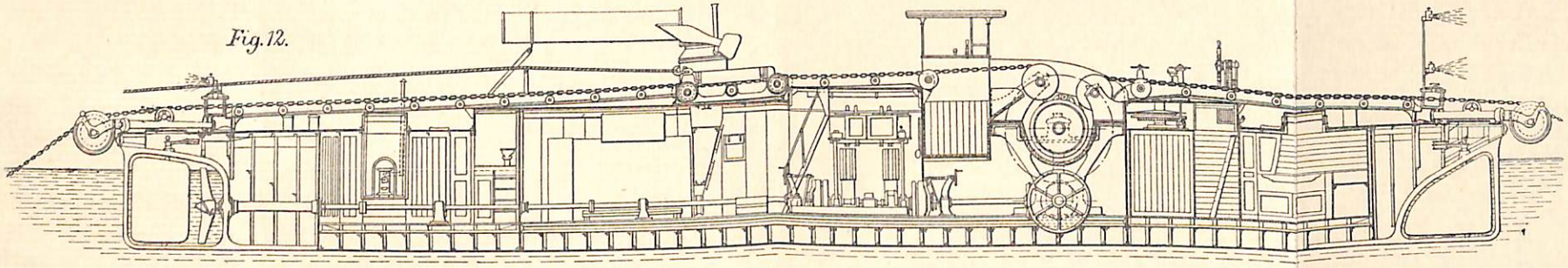


Fig. 16.

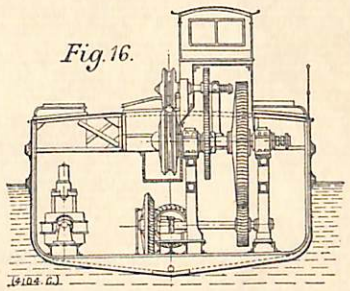


Fig. 13.

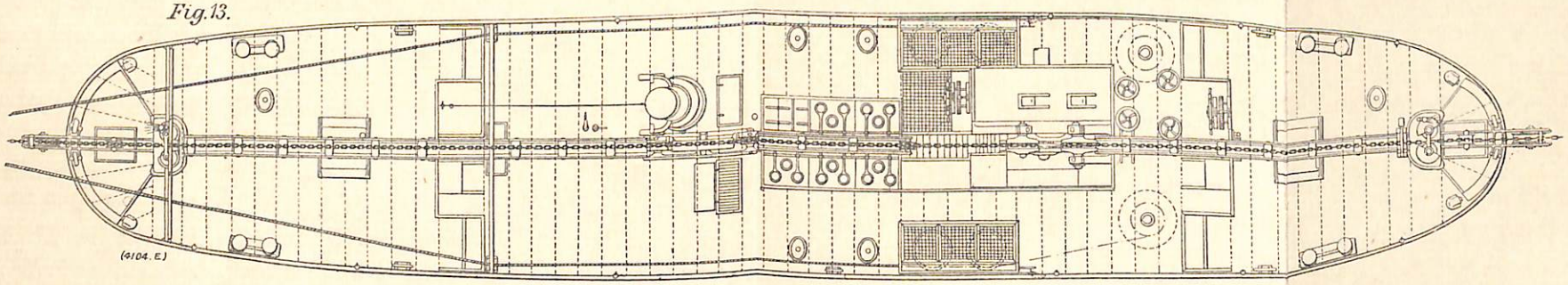
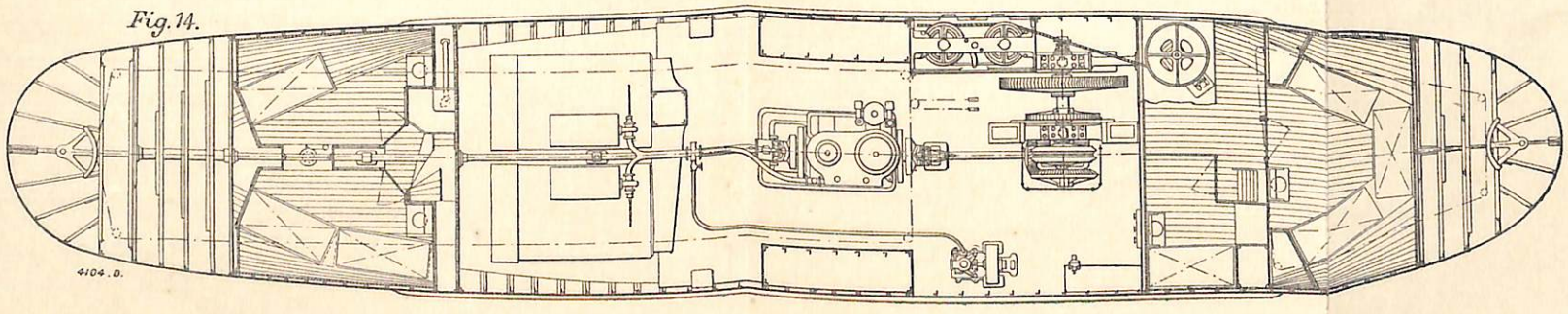


Fig. 14.



PARTICULARS.

Length ...	...101 ft. 8 in.
Breadth ...	... 17 ,, 11 ,,
Depth of hull ..	... 10 ,, 2 ,,

ENGINE:

Diameter of high-pressure cylinder	... 14.76 in.
Diameter of low-pressure cylinder	... 25.98 ,,
Length of stroke	... 15.75 ,,
Power developed on screw	... 150 H.P.
Number of revolutions	150
Power developed on the chain	100 H.P.
Number of revolutions	100

BOILERS:

Total heating surface	1,119 sq. ft.
Working pressure ...	113 lb. per sq. in.

the latter. The engine is designed for working at different speeds; the normal being 150 revolutions when driving the screw, and from 70 to 90 when working the chain gear. When developing 150 horse-power at 150 revolutions, the consumption of fuel is 2.2 lb. per horse-power. A point of much importance should be referred to here. It may be assumed that for some reason or other the chain tow-boat has been obliged to stop in mid-current, where the velocity is at a maximum. The boat stops upon its chain; the whole convoy, also, of course, in mid-current, throws the whole of its weight upon the tow-boat. After the cause of the stoppage has been removed, it will be necessary to make a fresh start and gradually to attain the normal speed. This re-starting of the driving machinery, at a time when it has to overcome the maximum resistance, is usually effected without difficulty when the motor is a two-cylinder coupled engine, but the operation may be difficult when it is a compound engine; just a somewhat similar difficulty occurred with the first two-cylinder compound locomotives. Precautions to be taken for stopping and starting are thus rendered necessary by the fact that the motor of the chain-tow-boat, under consideration, is a compound engine. To facilitate the operation, a shifting gear worked by hand is employed, by which high-pressure steam is admitted direct into the large cylinder. It would be preferable on boats of this class to have an independent motor for the screw, and one for the chain, and the arrangement we have described was adopted only on grounds of economy; as a matter of fact, however, the single engine has satisfied all requirements. The chief defect is, that having available a much higher power than is necessary for chain haulage, the crew are tempted to run too fast, and so incur a serious danger of breaking the chain; but it is possible to check this by attaching a speed recorder on one of the chain shafts.

There are also placed in the engine-room the following apparatus: (*a*) A dynamo and motor for furnishing the current to the various magnetised devices. The engine has two cylinders, and may be worked single or compound; it can exhaust into the condenser of the main engine, or into the air, as may be most convenient. This installation furnishes from 30 to 40 amperes, with a consumption of 18 kilogrammes of steam per electrical horse-power, when exhausting into the condenser. The maximum power when exhausting into the air is 60 amperes, but with a considerably higher consumption of steam. (*b*) A distribution board attached to the forward bulkhead; the conductors are laid within wood casings, and the resistances are placed on the right of the chain well. (*c*) An ejector used for filling and emptying the aft compartment of water-ballast; for removing water from the hull and from the chain and pulley

Fig. 17.

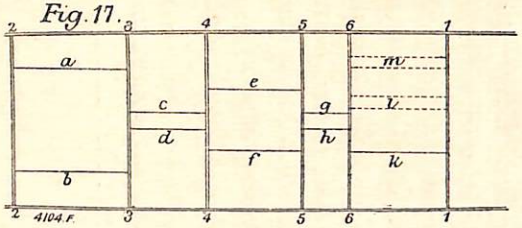


Fig. 18.

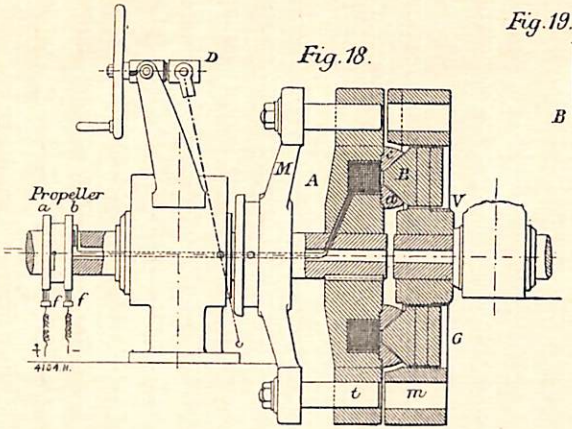


Fig. 19.

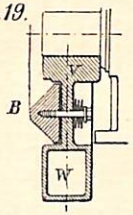


Fig. 20.

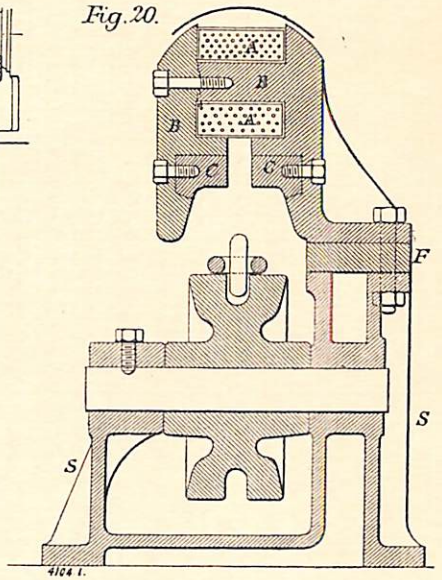


Fig. 22.

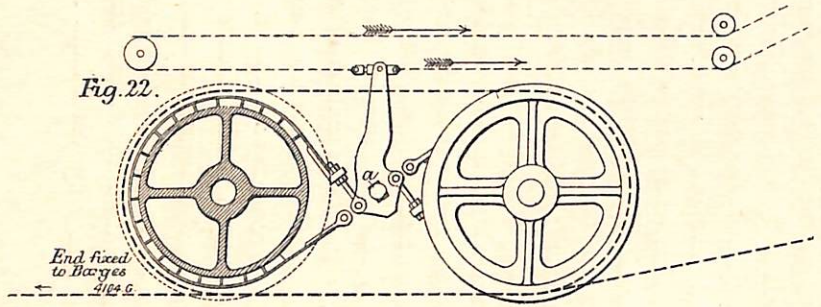
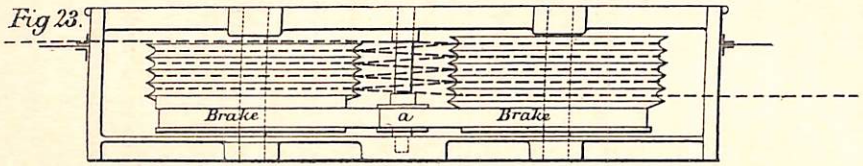


Fig. 23.



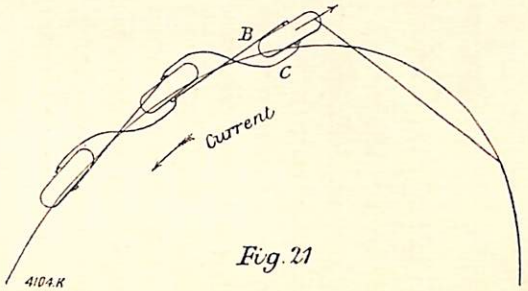


Fig. 21

well; for washing the deck and chain run, &c. There is a combination of valves by which these various services can be effected with the steam pump of the main engine. Reference was made above to the water ballast in the aft compartment. When running on the chain this compartment is empty, and the boat is practically on an even keel. When running with the screw the compartment is filled so as to bring the stern down sufficiently for the screw, which is 1.70 metres in diameter. The compartments on each side of the main engine have together a capacity of 11 cubic metres (388 cubic feet).

With the arrangements that we have described, when the boat is driven by the screw, the chain mechanism is thrown out of gear, the screw shaft clutch is coupled, and the dynamo is stopped. When working with the chain the screw is uncoupled, though it is desirable to be able to couple it again rapidly and without stopping the main engine, either to keep the boat straight if the chain break or run it together with the chain. It is true that at the slow engine speed necessary for the chain haulage, the screw cannot do much to propel the boat, but the wash from the propeller is thrown against the rudder, and helps the steering in turning round sharp bends. In order to facilitate coupling-up quickly, a magnetic clutch is added to the mechanical coupling.

The development of this magnetic clutch, of which a large number are now in use, was due to the experiments with the chain pulley already described. It has the advantage of great adaptability, and can be readily thrown on when running, without checking speed or setting up any shock. Such clutches are in service on engines up to 800 horse-power, and working at 100 revolutions. Figs. 18, 19, and 20 give a good idea of their construction. In these figures V is the flywheel of the engine; A, M, D are the parts of the ordinary mechanical clutch; excepting that the piece A, instead of consisting of two arms, is formed of a circular plate with two projections, in which holes are made for guiding the tenons *e*. In this disc A is cut a circular groove that holds a wire coil, the two ends of which, passing through the centre of the main shaft, are led beyond the shaft bearings to two terminals *a*, *b*. On this same disc are fixed the two jaws *c* and *d*, the whole, A, *c*, *d*, forming an electro-magnet that can be excited by the coil. The armature of this electro-magnet is a circular crown of wedge section B placed against the flywheel V of the engine; it is held in place by four sets of Belleville springs, arranged as shown in Fig. 19, and is capable of attraction to the surface of the electro-magnet and of being held there when the latter is excited. This piece B is driven by the flywheel through two projections that slide in grooves cut in the flywheel. When the electro-magnet is excited the armature becomes fast in the magnet, and the coupling is complete without the action of the mechanical clutch.

The chain traverses the deck longitudinally in the usual manner. Forward and aft are two switches, adapted to suit the oblique movement of the chain, and leading it to fixed vertical rollers, between which its position becomes fixed. Between these pulleys and the towing gear, the chain passes over a series of rollers placed in a water-tight trough that collects the drippings and detritus brought up from the bottom. The main tow pulley is almost hidden beneath the deck. One side of the casing containing it is placed far away enough to insure complete magnetic insulation; the casing itself is of wood, lined with zinc. The small taking-off pulley, which has but little work to do, is mounted on the end of its shaft, and has one face thoroughly insulated. The leading-in pulley has, on the other hand, to resist a considerable strain; on account of the change in direction it gives to the stretched chain, it is mounted on a shaft carried in strong bearings on each side. It is an ordinary cast-iron pulley, but it can be magnetised, and can be converted into a driving pulley by means of a toothed wheel on its shaft, gearing into another toothed wheel on the main shaft of the towing gear, which transmits movement to the taking-off pulley. The toothed wheel on the leading-in pulley-shaft can be shifted so that the pulley can be either idle or driving; it is magnetised only in the latter case. The object of the arrangement, which is not really necessary, is to obtain greater adhesion if required. Directly aft of the towing gear is the chain well, which is introduced to keep on board a certain amount of slack. To the well is added a chain brake that regulates the rate of discharge, and the quantity kept in the well. It consists of a straight electro-magnet, placed above the chain run. Fig. 20 shows it in transverse section. It is placed very close to the passing chain, and when magnetised attracts the latter; the rate of travel then depends on the degree of magnetisation, and the weight of the chain aft of the brake. On the frame of this brake is mounted the hook used for attaching a tow when the boat is running with the screw. An examination of the drawings will show that when it is desired to take the boat off the chain the latter need not be divided, but the whole of the towing gear can be shifted to one side of the boat. For this operation it is only necessary, by means of the brake, to accumulate 3 or 4 metres of slack in the chain well, and to put stoppers on the chain at the switches fore and aft. Of course the boat has to be stopped, but the whole operation does not take more than ten minutes.

The captain has under his hand the steering wheel of the after rudder and the commutator lever, with which he can turn on and regulate the

current for the various magnetic devices. The main and taking-off pulleys receive 5, 25, or 35 amperes; the brake can receive 3, 6, 9, or 12 amperes; the magnetic clutch of the screw is thrown in by pressing a button, without any variation in the current. The forward rudder is in charge of one of the crew, who also controls the various towing devices, about which a word should be said. The convoy is always attached by two cross cables, and these require some manipulation, to insure its taking a proper course. Fig. 21 is a diagram, showing a tow passing round a bend; the sketch shows the operation, the cable B being tightened, and C slacked; if the bend was in the other direction the manœuvre would, of course, be reversed. Usually very large and heavy hemp cables are employed (they weighed $5\frac{1}{2}$ kilogrammes per metre on the boats of the Compagnie du Touage de la Basse Seine et de l'Oise), and there is a good reason for this practice. It may happen at the moment of starting, either because the engine is not in good working condition, or from some fault of her engineer-in-charge, that the motor may start at too high a speed. In such a case with a tug-boat the screw churns up the water violently, but no serious damage can be done. In the case of a chain tow-boat, the forward movement of which corresponds absolutely with the winding up of the chain, if this latter is wound up too suddenly it happens, in case of bad management, that a shock transmitted to the boats in tow might be attended with disastrous consequences. Hence the necessity of taking special precautions either by the use of very heavy cables, or by the application of an elastic apparatus to absorb the shock. The heavy cables absorb the effect of this shock to a remarkable degree, and thus provide a simple but very effective method of protecting them. On the boats we are describing, an interesting experiment has been made by the use of light steel cables, combined with an elastic device, to absorb the shock. This arrangement is shown in Figs. 22 and 23; it consists of a double-grooved drum, similar to the old chain-haulage pulleys. The cable takes four half-turns on each drum, and the end is rolled around a supplementary store drum. The two drums are held up by means of a brake, the arrangement of which constitutes the novelty of the system. As will be seen in Fig. 22, the brake consists of a band, lined with blocks of wood, and having its heads jointed to the head of a crank free to move around a vertical axis a, and having a small amount of play in the direction of the tangent common to both pulleys. In this way the compensating action is automatic; the pressure is progressive as the boats forming the convoy are added, and as they move forward the required elasticity is obtained. When travelling the brakes are locked hard, and if it is desired to slacken one of the cables it

Fig. 24.

is sufficient to release the brake; the storage cable supplies the additional cable required, a light brake checking the tendency to unwind more than is required. On the tow-boat the bollards and storage drums are fixed under the deck, as is shown in the drawings, in such a way that all the necessary operations are controlled by four handwheels placed near the wheel of the forward rudder. Fig. 24 is a general view of the boat we have described, and shows the forward leading-in pulley, the towing apparatus, and the leading-out-trough.

The tow-boats that we described previously have given complete satisfaction on the Seine; the first was put in service four years since, and the remainder at later intervals. The vessel we illustrated combines all the modifications suggested by experience. We made a reference to the amount of wear on the towage pulley, measured after a year's work—wear that was so small as to be practically negligable; this clearly proved that there was no slip between the pulley and the chain, in spite of the fact that links from time to time become twisted, and therefore do not pass over the pulley truly. In this connection it may be added that at some periods of the year, especially in summer, and in the vicinity of St. Denis, the river is heavily charged with mud and sewage. At such times the chains slip over the pulleys of the ordinary boats, but never over those electrically controlled. It was found that the taking-off pulley works admirably, and although but little special care has been taken with the installation of the electric gear, so as to protect it from the shocks inherent to starting and stopping, no difficulty has been experienced with maintenance. Besides injuries arising to this part of the apparatus from mechanical causes, trouble might also come from heating due to the current, but no indications of this have been observed. Economy in working appears to be clearly proved by the following figures. The company to which reference has already been made employed, during 1896, five ordinary chain-hauled tugs, and three on the electro-magnetic system; the gross daily receipts of these latter were 21 per cent. more than those of the former, while the crew of each boat consisted of six instead of seven men. The benefit thus gained is due to the fact that the material can be used in both directions, but in making a comparison several points have to be considered. The electro-magnetic tug has to be debited with the steam used in driving the motor of the dynamo; but it saves the wear and tear of the winches and chains in the ordinary system; these two may be assumed to balance. The efficiency measured by taking the ratio between the work done in the steam cylinders, and that utilised on the tow-ropes of the convoy—the work done in propelling the boat itself being

lost—is approximately 70 per cent., this being the average of a number of experiments. The problem of placing in service a chain-haulage tug-boat (*toueur remorqueur*), under entirely satisfactory conditions, thus appears to have been satisfactorily solved. It is needless to say that the type of boat may be varied according to special conditions. What actually characterises the system is the method of hauling on the chain. Upon the Seine, where a relatively large draught of water prevails, it was convenient to adapt it to a boat provided with a screw propeller, but it would have been equally efficient if the motive power were a stern-wheel, water jet, or sidewheels, or if no supplementary means of propulsion were added—a condition desirable under certain circumstances. The boat we have described possesses a large amount of tractive power, although the Seine is on the whole favourable for navigation; but during periods of flood there is a very rapid current, and the convoys are in almost all cases made up of boats badly adapted for towing, and of defective contruction. For these reasons it is desirable that an ample margin of power should be provided. In the case of more rapid currents and with heavy tows, the tractive power required would be greater than on the Seine, but in such a case the chain would be heavier, and its greater weight would increase the adhesion to the pulley. The necessity of using a heavy chain, which is an essential condition of good working with chain haulage, agrees exactly with the adoption of magnetised pulleys. Whatever may be the tractive effort required, there does not appear to be any reason for making the diameter of the pulley very large, and 1.50 metre is a limit which there seems no reason to exceed. In small towing gears this diameter may be decreased to 50 or even 40 centimetres, so that while the maximum sizes are not excessive, the smaller ones are quite unimportant. With so wide a range of adaptibility to varying conditions, it would seem that this system of towing must find many successful applications where other existing system would be of little service. It often happens on natural water-courses that there exist long reaches of almost still water, separated by rapids that cannot be traversed by ordinary means; such obstacles can be readily surmounted by a small magneto-electric tow gear, carried on a tug, the chief work of which is to convey a train of boats over the reaches of still water. The device may even be attached to the side of the tug, for easily connecting with the chain when required; the ends of the chain laid down over the difficult passages can be secured to buoys, an arrangement that facilitates making the connection. In the case of small water-courses presenting difficulties along their whole length, and of but little depth this

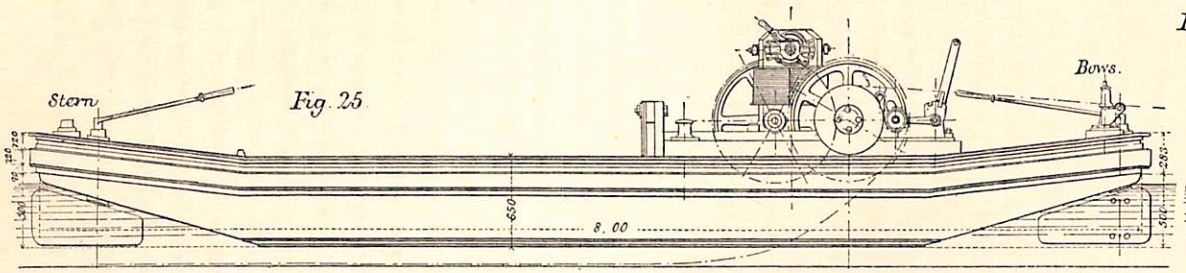


Fig. 25.

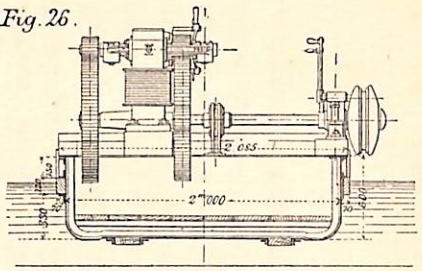
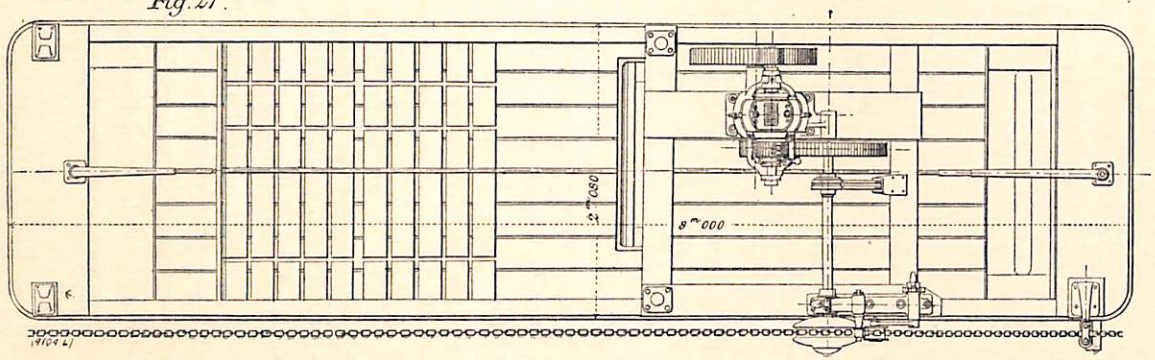


Fig. 26.

Fig. 27.



method of chain haulage is possible even for an insignificant traffic, because the system as described is susceptible of being reduced to a very rudimentary and simple form. In fact, the tow may consist merely of a raft with a pulley of 50 or 60 centimetres diameter, and transmission gear, with a 15-horse-power portable engine. Such an arrangement, weighing $2\frac{1}{2}$ or 3 tons, would be suitable for hauling light convoys, weighing from 300 to 500 tons, at a speed of from $2\frac{1}{2}$ to 3 kilometres an hour, against a current of from 8 to 10 kilometres. The 14 or 15 tons weight of the tow raft would represent a draught of from 20 to 30 centimetres. A very interesting example of the adaptibility of this system is seen in the tow-boat installed by the Ville de Paris in 1896, for hauling boats along the main sewer under the Rue Royale; these boats are used chiefly for visitors and inspectors. The hull of this tug is 8 metres (26 ft. 3 in.) long, 2 metres (6 ft. 7 in.) wide, and 60 metre (23.62 in.) depth of hull; it is illustrated by Figs. 25 to 27. The towage pulley is placed forward and outside the boat; it has a diameter at the bottom of the groove of 45 centimetres, and is driven by an electric motor through gearing. The current terminals are on the pulley shaft, between the pulley and the spurwheel on the shaft. The chain passes on to the boat between two vertical guiding rollers, and thence to the pulley round which it is turned for about 270 deg. The chain is held to the pulley by a small guiding pulley mounted on a bent lever, which can be thrown into contact, or raised when it is desired to take off the chain. This pulley, which is heavy and of cast iron, is magnetised by derivation, and assists in taking off the chain by a non-magnetic lever attachment. The coil is formed with 2850 turns of wire 1.44 millimetres in diameter, and receives a current of 3.15 amperes and 100 volts. The current is furnished to the dynamo by accumulators (Fulmen type) that are placed in the after-part of the boat, and arranged in two groups of 60 cells in all, which can be coupled either in quantity or tension. The current in the sewer is about 1 metre per second (say 2.25 miles an hour), and the tug with six boats, approximately following the section of the sewer, can make a speed of 2 kilometres an hour, involving a tractive effort of 700 kilogrammes (15,400 lb.). When the convoy has reached the terminus, the chain is thrown off, and the convoy descends on the cement; or if this is insufficient it is assisted by another small tug behind, of a similar arrangement but of much smaller dimensions (4 metres long and 2 metres wide), which takes its current from the battery on the main tug, through a cable led over the string of boats. When working, the dynamo of the larger tug absorbs 60 to 65 amperes at 65 volts; that of the smaller, 23 amperes. The chain pulley of the latter

is 45 centimetres in diameter, but is of cast iron; the chain used weighs 5 kilogrammes per metre. Before this installation was in use, the trains of boats were hauled by hand, and involved the labour of sixty men. The electric system, as employed on the Seine, and that in use on the Rue Royale sewer, represent the two extreme cases to which it has been successfully adapted, and illustrate the most complicated and the simplest forms, equally well suited to most conditions of heavy and light traffic.

The tow-boats that we have previously described are especially adapted for hauling barges over natural channels. To secure the most economical results, the traction ought to be supplied to the convoys as continuously as possible. This favourable condition is found on rivers either in their natural state or regulated, and usually only interrupted by locks of large dimensions and at long distances apart. But the conditions are very different for the most part on canals, where locks are generally numerous, and not large enough to receive a convoy; the length of the reaches is also, as a rule, very unequal, and under these conditions the haulage of long tows becomes impracticable. Where it is necessary to lock the boats one by one, it is evident that the difficulties of economical haulage in groups becomes excessive; and for this reason the use of horses has been hitherto found most advantageous, in spite of the numerous experiments in mechanical traction that have been made. The chief obstacle has arisen from the necessity of dividing among a large number of barges the small and independent units of power necessary for each. The first cost of any such installation must unavoidably be large; and, in order to compete with the cheaper horse traction, the expenses of working must be very low. For this reason, those systems of mechanical haulage that require the employment of an additional man on each boat involve additional cost, and thus render them inapplicable. Towing by light locomotives running on rails laid upon the canal bank possesses many well-defined advantages, but is attended with other difficulties besides that of excessive cost. It is not a part of the scheme of this work to consider the relative advantages and drawbacks of the various methods of mechanical haulage on canals; and we refer to them simply as an introduction to a method which has recently been tested on the St. Denis Canal, and which is a modification of the Bovet system that we have described. About forty years ago a Monsieur Bouquier suggested a solution to the problem of mechanical traction for canal boats. He proposed to place on board each barge an apparatus consisting of a portable engine driving a paddle-wheel by a belt; this wheel was mounted so as to project from one side of the boat. Arrangement was made by which the whole device

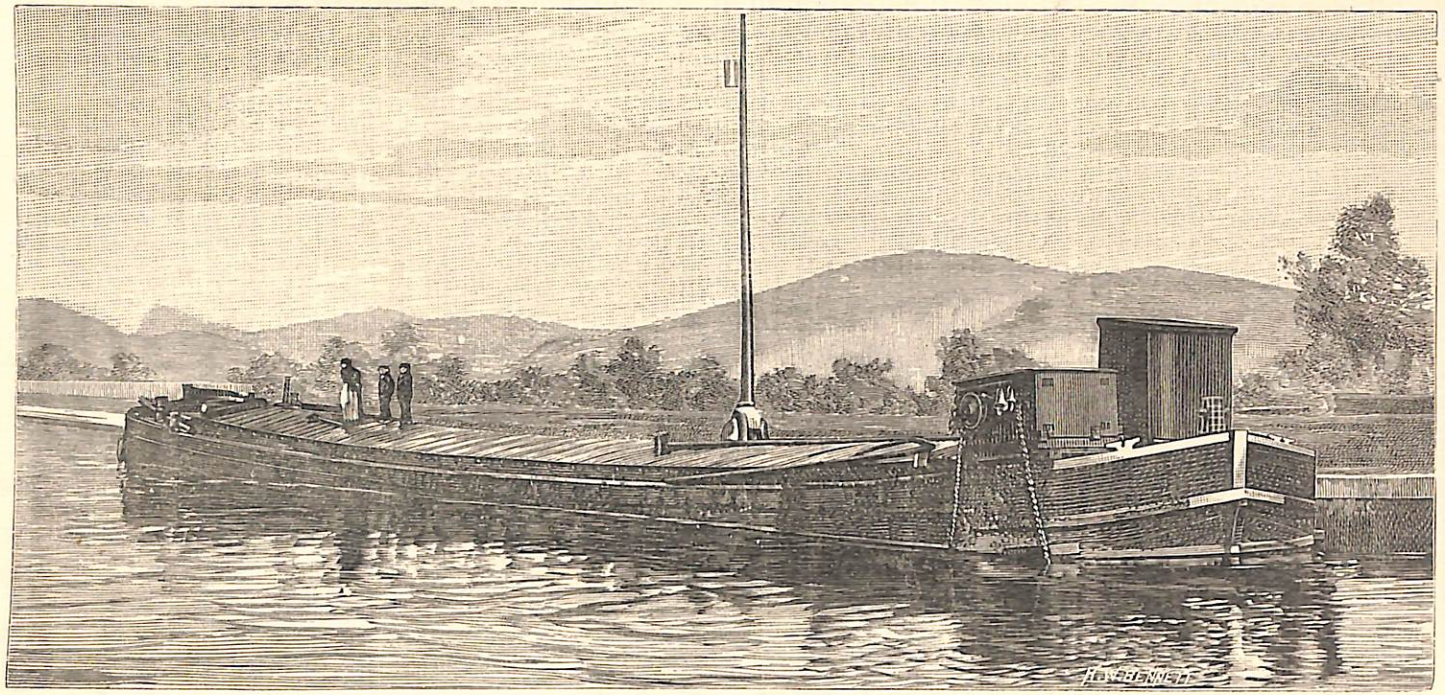


FIG. 28.

could be easily shifted from one boat to another, so that a maximum of work could be obtained with one plant. Numerous trials of this system were made, but it was ultimately unsuccessful, on account of the difficulty of tran-

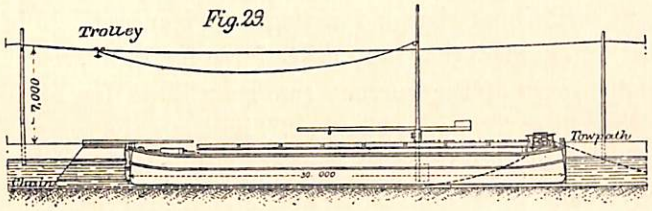


Fig. 23.

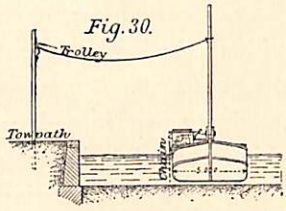


Fig. 30.

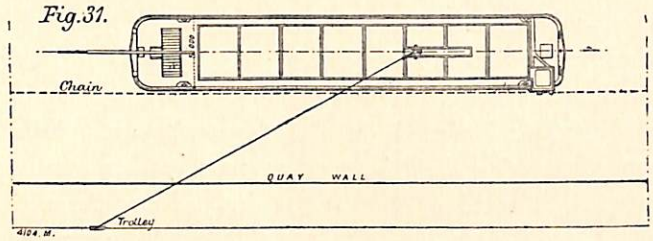


Fig. 31.

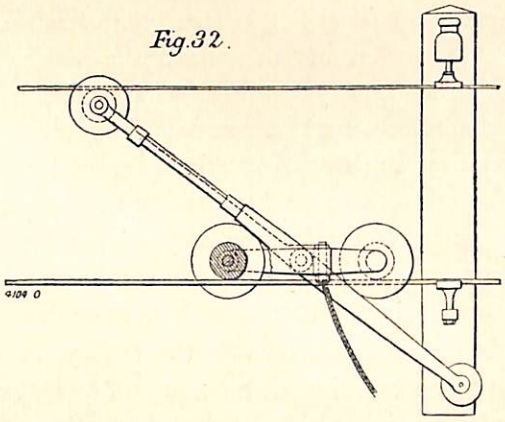


Fig. 32.

shipping the motor, and the cost of working. Monsieur de Bovet has, however, under widely different conditions, followed the lines of Bouquier, substituting an electrical for a mechanical motor. By this arrangement he has reduced the weight of the apparatus to about a ton, which does not appreciably reduce the carrying capacity of the boat. In the arrangement adopted,

no projection from the boat affects its width, so that the barges can be built as wide as the dimensions of the locks permit; this is an important detail, as it affects the prices charged for carrying freight. The management of the electric motor is so simple that it can be entrusted to one of the boat's crew, so that no additional charge for wages is incurred. It is evident that electricity is better adapted than any other force for sub-division to actuate small powers, and a part of the current can be utilised for magnetising the two pulleys. Figs. 28 to 32, pages 26 and 27, indicate the way in which the plan has been experimentally tried on the St. Denis Canal. The barge employed carries about 300 tons, and is of the standard type used on the canals in the north of France. It is an unsightly structure, and offers a maximum resistance to towage. On the other hand, it is cheap to construct, and contains the greatest room for stowage; the type is, in fact, one that has been evolved by experience. The towage gear and its motor are enclosed in a sheet-iron box, and placed on the forward part of the boat, on a tripod frame, each leg being held by screws to the floor of the barge. The box is free to slide inboard on the frame in passing through locks. The current is brought to the motor from a cable carried on posts along the canal bank, there being a trolley running on the cable. From the trolley passes a flexible cable that extends to a mast on the barge; this cable is led over a pulley, and down the mast, and thence to the towing gear. At the bottom of the mast the cable is wound over a compensating drum, which always preserves a sufficient margin of cable to compensate for deviations in the course; the drum is controlled by a spring that winds up any slack that may have been drawn off. This means of regulation is necessary, as the mast has usually to be removed in going under bridges, and the cable has to be raised when passing other boats. It has been proved that this arrangement is much more satisfactory than a permanent trolley; not only because it must be placed high enough to clear obstacles met, such as masts, funnels, etc., but also because the trolley cannot be kept to a line over the boat, nor even on one side, as on many of the Brussels tramways, on account of the irregularities in width of water, formation of banks, etc. It has not been found practicable to make use of the submerged chain for the return circuit; the resistance is too great. This was clearly proved by the earlier experiments, and it was found necessary that there should be a return cable, and consequently that two trolleys must be used. Those that were first used, and answered well, were made with two deep grooved wheels on a counterweight; one of these trolleys was drawn by the cable and hauled the other. Of course,

there are various ways of making such trolleys, dependant on the special conditions. One satisfactory form is shown in Fig. 32. It consists of one trolley running on the lower line, and carrying a smaller trolley bearing on the upper cable, either by means of a lever and counterweight or by a spring. This trolley is not liable to derailment, and the man in charge of the boat has one trolley, instead of two, to look after. The upper trolley can be easily shifted

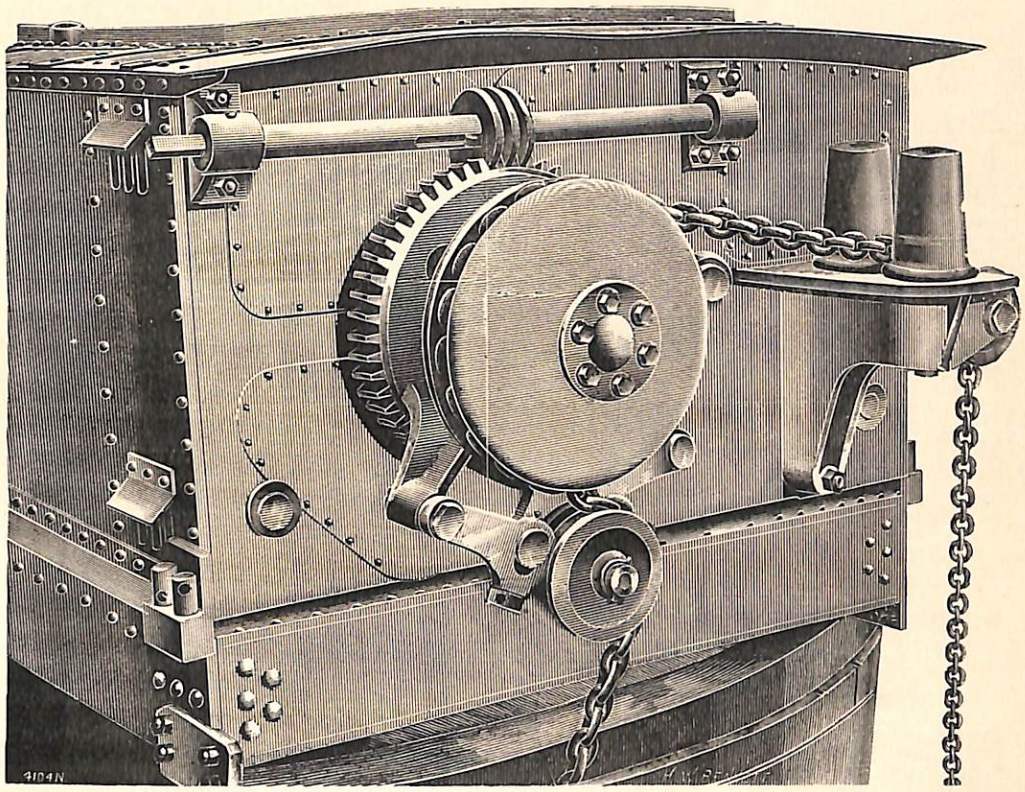


FIG. 33.

and the boat stopped; or if the way has to be cleared, the whole device can be brought inboard by means of a boat-hook.

The tow gear that has been used consists of an electromotor running at 1000 revolutions, and driving an intermediate shaft by contact between a cast-iron flywheel and a magnetised friction roller; from this countershaft the transmission to the tow pulley is by gearing. The diameter of the tow pulley at the bottom of the groove is .40 metre, and the normal speed at which

Fig. 34.

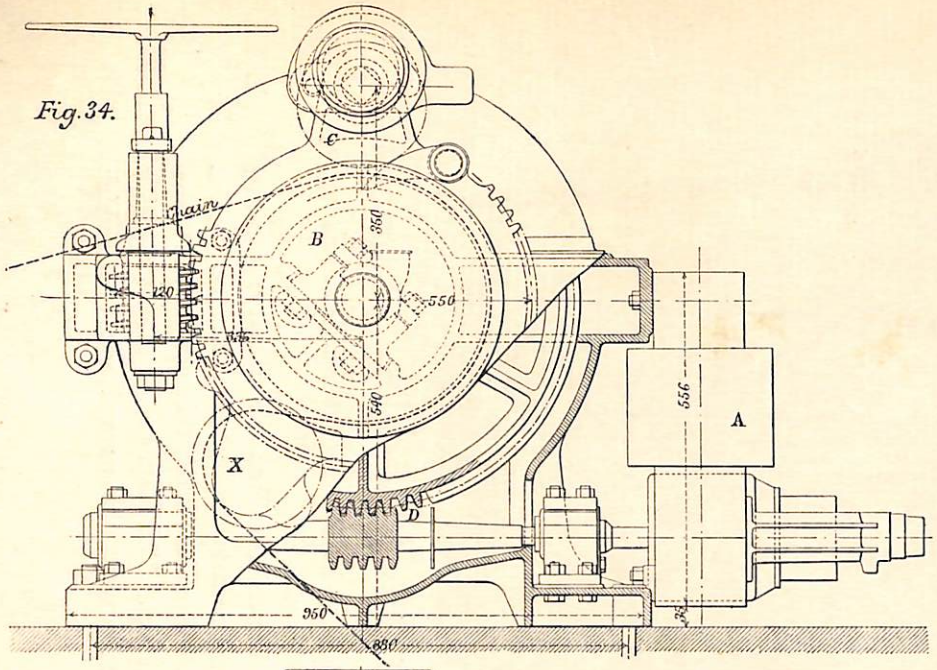


Fig. 35.

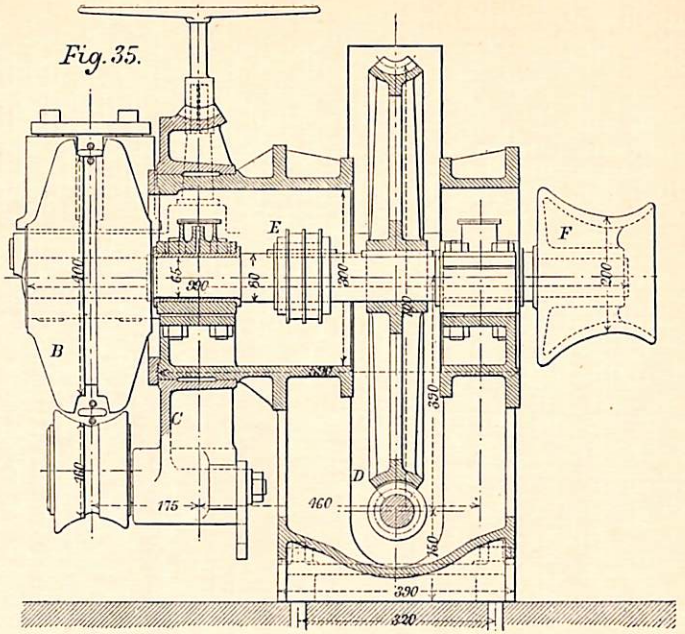


Fig. 36.

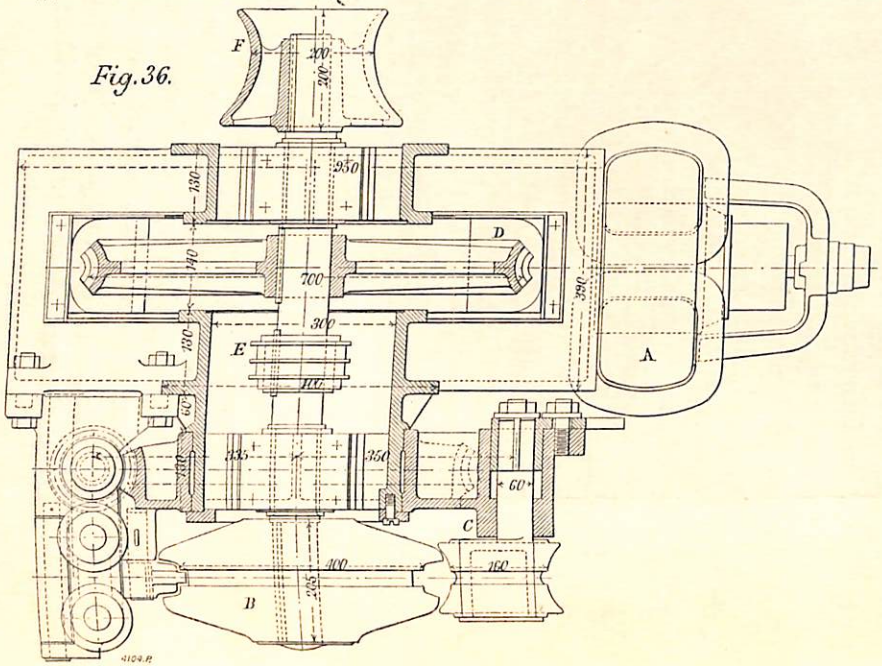
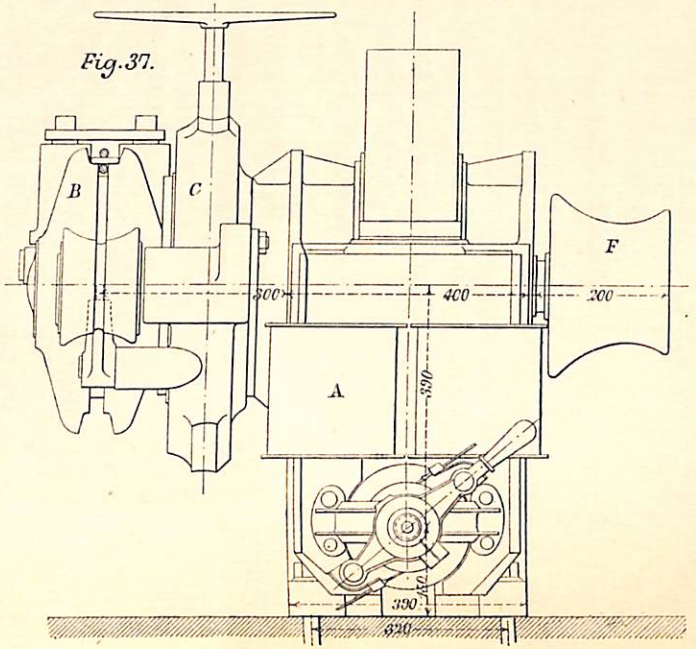


Fig. 37.



it is driven is 40 revolutions, corresponding to 3 kilometres an hour. As in the Rue Royale sewer installation, already described, the chain rising from the water is guided by a heavy roller, the chain being assisted to leave the magnetised pulley by means of an insulated, or non-magnetic, metal lever. This lever and the guide roller are mounted on an eccentric wheel controlled by an endless screw to regulate the angle of winding round the tow pulley; this can be as much as 270 deg., or reduced to nothing when it is desired to throw off the chain. The Figs. 28 and 33 illustrate the installation very clearly the latter is an enlarged view of the towing device, and the former a general view of the barge fully equipped. It should be mentioned that the wooden shelter shown on the barge was erected to protect the measuring instruments used during the experiments, and does not form any part of the installation. The barge, with a load of 300 tons, was hauled at a speed of from 2.8 to 3.0 kilometres per hour, with a current of 20 amperes and 110 volts at the station. At starting the current rose to 60 amperes, and then fell gradually, the normal rate being reached when the boat had traversed 80 metres. No difficulty was experienced with steering, in spite of the fact that the tow gear was on one side of the boat, and the trolleys gave no trouble. The conducting cables were needlessly heavy, being adapted for a current of 110 volts; they would have been, of course, much lighter for a 500-volt current. The experimental apparatus we have described and illustrated would be considerably modified for regular service, and a standard type is shown by Figs. 34 to 37. The tow pulley, and the vertical leading-in roller, the guide pulley, and the detaching lever, with its eccentric movement, are used (the guide pulley and lever are shown on the engravings by dotted lines for the working position). The transmission between the electric motor and the tow shaft consists of toothed gearing, and an endless screw running in oil and fitted with ball bearings. At the opposite end of the pulley shaft is a drum, the diameter of which is one-half that of the pulley. By passing a rope over this drum, a ready means is available of obtaining sufficient hauling power for entering locks, which are generally but little wider than the boat. Such an installation as we have described involves the establishment of the double line of cable on each side of the canal, one for up and the other for down traffic, and the sinking of two chains, which may, if desirable, be laid in the locks. It is, however, so simple to throw off and take on the chain, that it is generally better to handle the boat by means of the rope and drum referred to above.

The several applications of the Bovet system which are described, prove the possibility of utilising magnetic attraction for the development of con-

siderable efforts; and it may be readily seen that the useful variations of this method may be numerous. In the course of the investigations he has made while pursuing the question of electric towage, M. de Bovet has been led aside in certain important deviations, especially with regard to transmission of power and magnetic brakes; these have been very fully described in the Transactions of the Société Internationale des Electriciens, of Paris.

PRINTED AT THE BEDFORD PRESS, 20 AND 21, BEDFORDBURY, STRAND, LONDON, W.C.

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